

# Microstructural Analysis of AM50/Mg<sub>2</sub>Si Cast Magnesium Composites

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## Abstract

AM50/Mg<sub>2</sub>Si composites containing 5.7 wt. % and 9.9 wt. % of Mg<sub>2</sub>Si reinforcing phase were prepared successfully by casting method. The microstructure of the cast AM50/Mg<sub>2</sub>Si magnesium matrix composites was investigated by light microscopy and X-ray diffractometry (XRD). The microstructure of these composites was characterized by the presence of  $\alpha$ -phase (a solid solution of aluminium in magnesium), Mg<sub>17</sub>Al<sub>12</sub> ( $\gamma$ -phase), Al<sub>8</sub>Mn<sub>5</sub> and Mg<sub>2</sub>Si. It was demonstrated that the Mg<sub>2</sub>Si phase was formed mainly as primary dendrites and eutectic.

**Keywords:** AM50 magnesium alloy, Mg<sub>2</sub>Si, Magnesium silicide, Metal matrix composites

## 1. Introduction

Magnesium and its alloys owing their low density and relatively good mechanical properties have been widely used as structural materials mainly in automotive and aerospace industries. Advantageous strength to weight ratio of magnesium alloys and their excellent castability make them good candidates to use in die casting which assure good shape reproducibility in the final products. Recycling of these materials is much more convenient than recycling of plastics [1-4].

However, magnesium alloys also have a number of undesirable properties such as poor wear resistance, high chemical reactivity and poor corrosion resistance that have limited their applications in many branches of industry. Therefore, the improvement of the properties of magnesium based materials is needed [1-3,5]. Fabrication of magnesium alloy matrix composites with various reinforcing constituents is one way to achieve this goal [6].

It has been shown that the magnesium matrix composites with Mg<sub>2</sub>Si particles have a high potential because Mg<sub>2</sub>Si exhibits

interesting physical and mechanical properties [6]. The intermetallic compound, magnesium silicide, has a relatively high melting temperature (1085°C), a low density (1.99 g/cm<sup>3</sup>), a low thermal expansion coefficient (7.5×10<sup>-6</sup> K<sup>-1</sup>), a high hardness (4.5×10<sup>9</sup> N m<sup>-2</sup>) and a reasonably high elastic modulus (120 GPa) [7-12].

The addition of Si to molten magnesium lead to the formation Mg<sub>2</sub>Si phase in situ [6,13,14]. According to the Mg-Si equilibrium phase diagram [15] the maximum solubility of Si in Mg is only 0.0033 wt.% at 639°C, and eutectic is formed at 1.48 wt. % of Si and at a temperature of 637°C. For hypereutectic Mg-Si alloys the primary Mg<sub>2</sub>Si phase has dendritic or polygonal shapes, while the Mg phase surround this constituent. On the other hand, the Mg+Mg<sub>2</sub>Si eutectic is formed as fully divorced with rod-like Mg<sub>2</sub>Si distributed in the continuous matrix. Various characteristics of Mg/Mg<sub>2</sub>Si composites, especially mechanical properties, corrosion resistance and castability, are dependent on a form of Mg<sub>2</sub>Si in which it exists in a particular material [10,14,16-19]. Thus, microstructural characterization of Mg/Mg<sub>2</sub>Si composites is of major importance. The present work is focused on the microstructure of magnesium matrix composites

with  $Mg_2Si$ , fabricated on a basis of AM50 alloy. The microstructure of AM50/ $Mg_2Si$  was investigated by light microscopy (LM) and phase identification was performed by X-ray diffraction method (XRD). Thermodynamic calculations were carried out to support experimental data.

## 2. Experimental materials and procedures

The composition of AM50 magnesium matrix alloy is listed in Table 1. To fabricate Mg-Al/ $Mg_2Si$  composites AM50 alloy ingots were re-melted at 680°C and then a desired amount of a pure silicon powder was added into the melted alloy into a crucible. The composites were gravity cast into a metal mould. For comparison purposes, AM50 alloy was cast at the same conditions. The silicon content in resulted composites was determined by atomic absorption spectrometry. The content of  $Mg_2Si$  in the fabricated composites was calculated with the assumption that silicon exists in them only as  $Mg_2Si$ . Two kinds of composites containing 5.7 wt. % and 9.9 wt. % of  $Mg_2Si$  were fabricated.

Table 2.

Chemical composition of AM50 alloy according to ASTM B93-94

Chemical composition [wt.%] <sup>*)</sup>							
Alloy	Al	Mn	Zn	Si	Fe	Cu	Mg
AM50	4.5-5.3	0.28-0.5	max 0.02	max 0.05	max 0.004	max 0.008	rest

<sup>\*)</sup> Mg rest

For LM examinations, composite samples were ground on waterproof sandpaper (a grinding size down to 4000) and then polished on polishing cloth with a lubricant containing 0.1  $\mu m$  diamond particles (Buehler, U.S.A.). Samples were etched in 1% solution of concentrated nitric acid in ethanol for 5 second. An Olympus GX51 light microscope equipped with an Olympus UC30 camera was used for LM observations. XRD measurements were performed on a Bruker D8 Advance diffractometer.  $Cu_{K\alpha}$  X-ray radiation was applied. Phase identification was conducted with a help of PDF4+ (2011) data base (The International Centre for Diffraction Data, Denver, U.S.A.). For thermodynamic calculations Thermo-Calc Software System from Thermo-Calc Software AB (Stockholm, Sweden) was used.

## 3. Results and discussion

Fig. 1 presents a typical microstructure of the as-cast AM50 magnesium alloy. The following microstructural constituents are visible: (i) primary  $\alpha$ -phase (i.e. a solid solution of alloying elements in magnesium), (ii) divorced eutectic  $\alpha+\gamma$  (where  $\gamma$ -phase is consisted of  $Al_{12}Mg_{17}$  intermetallic compound) and (iii) most likely  $Al_8Mn_5$ . The observed microstructure is a result of strong microsegregation of alloying elements, which is

characteristic for most of magnesium alloys solidifying in non-equilibrium conditions.

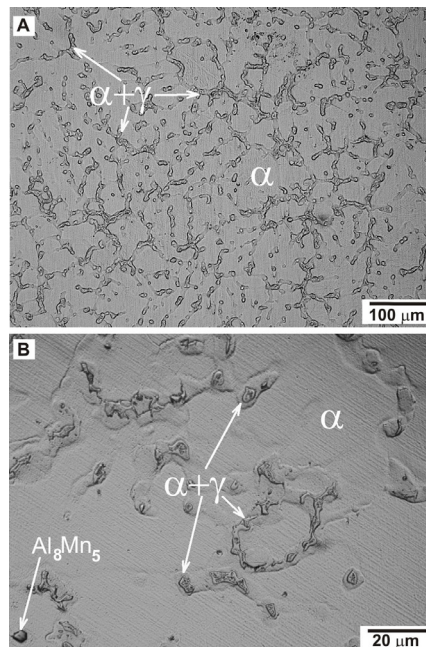


Fig. 1. Microstructure of as-cast AM50 magnesium alloy (LM).

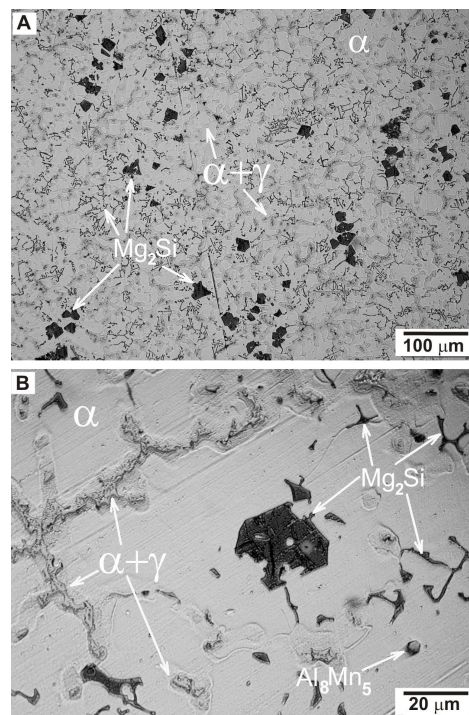


Fig. 2. Microstructure of as-cast AM50/5.7 wt. %  $Mg_2Si$  magnesium matrix composite (LM)

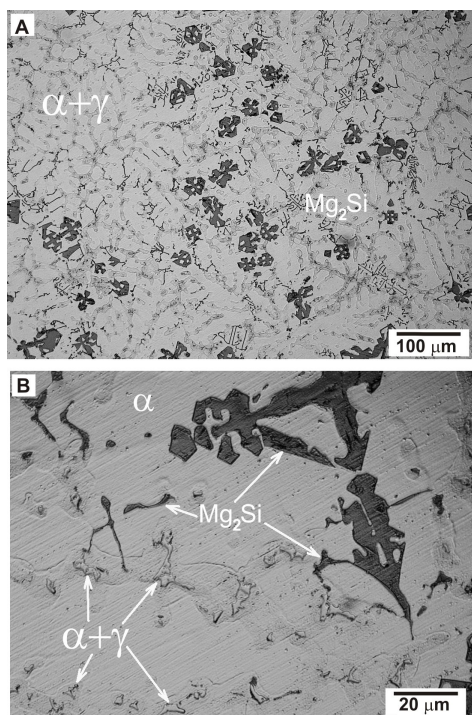


Fig. 3. Microstructure of as-cast AM50/9.9% wt.  $Mg_2Si$  magnesium matrix composite (LM)

The microstructures of the fabricated AM50/ $Mg_2Si$  composites containing 5.7 wt. % and 9.9 wt. %  $Mg_2Si$  are shown in Figs. 2 and 3, respectively. All microstructural constituents which are present in the parent alloy are also present in the composites' matrix. In the both fabricated composites, two distinct morphologies of a  $Mg_2Si$  phase are observed. Namely,  $Mg_2Si$  is present in a form of relatively large (several  $\mu m$ ) dendrites and eutectic. It comes from LM observations, that reinforcing phase is uniformly distributed in a whole volume of the matrix.

To get a better insight into the solidification process of the investigated materials, the phase diagram was calculated for the Mg-Si binary system at constant concentrations of Al and Mn which are equal to 5 wt. % and 0.45 wt. %, respectively. Calculations were performed for equilibrium conditions. A fragment of the phase diagram between liquidus and solidus temperatures is shown in Fig. 4. According to this diagram after the solidification the composite containing 5.7 wt. %  $Mg_2Si$  should be consisted of  $\alpha + Mg_2Si + Al_8Mn_5$ , whereas the composite containing 9.9 wt. %  $Mg_2Si$  should be consisted of  $\alpha + Mg_2Si + Al_3Mn_2$ . It should be noted that according to the equilibrium phase diagram the  $\gamma$  phase is formed from the solid state, as secondary precipitates, below solvus temperatures which are equal to 525.5K and 531.5K for the composites containing 5.7 and 9.9 wt. % of  $Mg_2Si$ , respectively. To analyze the solidification in non-equilibrium conditions, the solidification curve (Fig. 5) was calculated according to the Scheil model. The solidification starts from the formation of the primary  $Mg_2Si$  phase, like in the case of equilibrium conditions, but finishes with the ternary  $\alpha+\gamma+Mg_2Si$  eutectic transition which is consistent with the observed microstructure (Fig. 3).

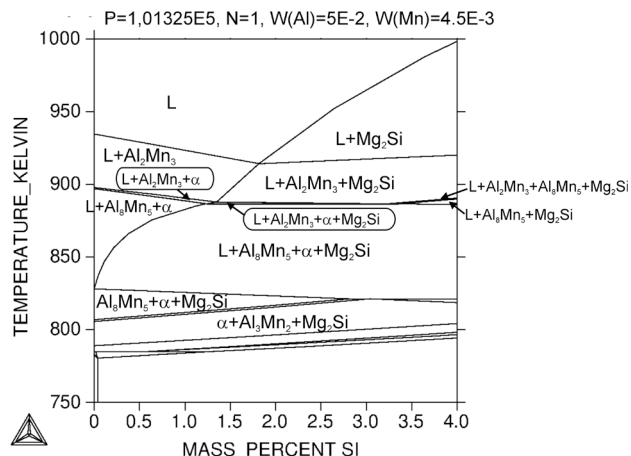


Fig. 4. Fragment of the Mg-Si phase diagram calculated at constant concentrations of Al (5 wt. %) and Mn (0.45 wt. %)

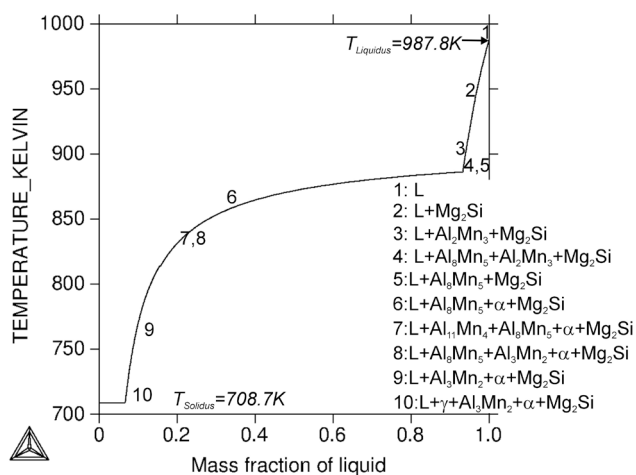


Fig. 5. Solidification curve of AM50/9.9% wt.  $Mg_2Si$  composite calculated according to the Scheil model.

In order to confirm the phase composition of the fabricated composites and the AM50 alloy, XRD analysis was performed. Fig. 6 shows X-ray diffraction patterns for the AM50 matrix alloy and the composites containing 5.7 and 9.9 wt. % of  $Mg_2Si$ . XRD data confirms the presence of  $\alpha$  and  $\gamma$  phases as well as  $Al_8Mn_5$  intermetallic compound in all materials. There are no reflexes originating from silicon which means that silicon reacted completely with magnesium forming  $Mg_2Si$ . Although, performed thermodynamic calculations indicated many changes in the composition of the Al-Mn phase, only  $Al_8Mn_5$  intermetallic compound was identified in the AM50 alloy and the composites by XRD.

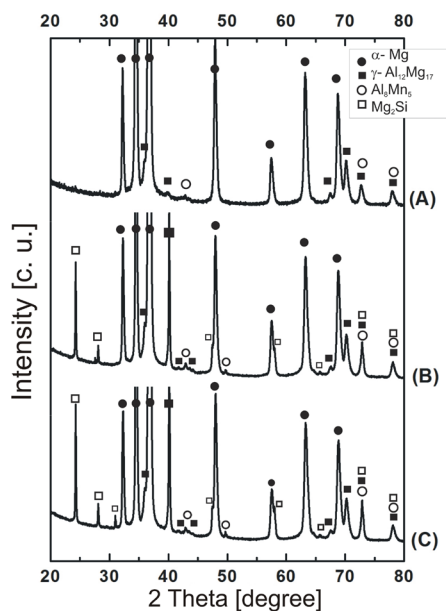


Fig. 6. X-ray diffraction patterns of (A) AM50 alloy and AM50/Mg<sub>2</sub>Si composites containing (B) 5.7 wt. % and (C) 9.9 wt. % reinforcing phase

## 4. Summary

The microstructural analysis of the AM50 magnesium alloy and Mg-Al/Mg<sub>2</sub>Si composites containing 5.7 and 9.9 wt. % reinforcing phase was presented. The results revealed that the microstructure of as-cast AM50 alloy was characterized by the presence of  $\alpha$  - phase and eutectic  $\alpha + \gamma$  (where  $\gamma$  is Mg<sub>17</sub>Al<sub>12</sub>) as well as Al<sub>8</sub>Mn<sub>5</sub>. The addition of silicon to the AM50 alloy caused the formation of the primary Mg<sub>2</sub>Si phase and the ternary eutectic  $\alpha + \gamma + \text{Mg}_2\text{Si}$ . The Mg<sub>2</sub>Si phase was uniformly distributed in a whole volume of the matrix.

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